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Specification

1. Invention Title

Solid State Light Emitting Device

2. What is Claimed is:

(Claim 1) A solid state light emitting device, wherein said solid state light emitting device is equipped with a base comprising a p-type boron nitride crystal layer containing a small quantity of Be and an n-type boron nitride crystal layer containing a small quantity of Si formed on the above p-type layer, granular phosphor layers consisting of grains with a 0.3 - 13 μ m grain diameter covering at least a junction between the p-type boron nitride and the n-type boron nitride crystal layers which appears on the sides of the base, and electrodes formed on an upper and lower surface of the above base, respectively.

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(Claim 2) A solid state light emitting device, wherein said solid state light emitting device is equipped with a base comprising a p-type boron nitride crystal layer containing a small quantity of Be and an n-type boron nitride crystal layer containing a small quantity of Si formed on the above p-type layer, thin film phosphor layers with a film thickness of $0.6 - 2.6\mu\text{m}$ covering at least a junction between the p-type boron nitride and the n-type boron nitride crystal layers which appears on the sides of the base, and electrodes formed on an upper and lower surface of the above base, respectively.

3. Detailed Explanation of the Invention

[Purpose of the Invention]

(Field of Industrial Application)

This invention pertains to improved solid state light emitting devices having a PN junction.

(Conventional Technologies)

In recent years, not only discharge tubes, but solid state light emitting devices are also widely used as electronics technology advances.

Conventionally, as a typical solid state light emitting devices, red light emitting devices with a structure as illustrated in Figure 2 is known in which an n-type GaP epitaxial layer 2 containing a small quantity of Te is formed on an n-type GaP crystal substrate 1, in which a p-type GaP epitaxial layer 3 containing a small quantity of Zn and O is formed thereupon, and in which furthermore, electrodes 4 and 5 are formed on p-type GaP epitaxial layer 3 and the back surface of aforementioned substrate 1, respectively. Moreover, although they are not illustrated in the figure, red light emitting devices employing a pn junction with GaAsP-GaAlAs on an n-type GaAs substrate, orange and yellow light emitting devices employing a pn junction with $\text{GaAs}_{1-x}\text{P}_x$ on the same substrate as above, green light emitting devices employing a pn junction with GaP on GaP as above, and blue light emitting devices employing a pn-junction with SiC on a SiC substrate are known.

These solid state light emitting devices have advantages in that they are small, and compatible with electronic circuits. On the other hand, however, the emission wavelength of solid state light emitting devices is restricted to that which is specific to each material system. Moreover, even if other emission colors are selected, it was difficult to obtain a desired emission color because solid state light emitting devices have very few varieties themselves.

(Issues to be Resolved by the Invention)

The invention is conceived upon giving considerations to the above circumstances. The purpose of the present invention is to provide a solid light emitting device having various emission colors while being equipped with the same PN junction.

[Constitution of the Invention]

(Means to Resolve the Issues)

In the first present invention, a solid state light emitting device is equipped with a base comprising a p-type boron nitride crystal layer containing a small quantity of Be and an n-type boron nitride crystal layer containing a small quantity of Si formed on the above p-type layer, granular phosphor layers consisting of grains with a 0.3 - 13 μ m grain diameter covering at least a junction between the p-type boron nitride and the n-type boron nitride crystal layers which appears on the sides of the base, and electrodes formed on an upper and lower surface of the above base, respectively.

In the second present invention, a solid state light emitting device is equipped with a base comprising a p-type boron nitride crystal layer containing a small quantity of Be and an n-type boron nitride crystal layer containing a small quantity of Si formed on the above p-type layer, thin film phosphor layers with a film thickness of 0.6 – 2.6 μ m covering at least a junction between the p-type boron nitride and the n-type boron nitride crystal layers which appears on the sides of the base, and electrodes formed on an upper and lower surface of the above base, respectively.

When the diameter of grains making up the granular phosphor layer goes outside the range of 0.3 - 13 μ m in the first invention of the present application, it is impossible to obtain an enough emission intensity. In the second invention, moreover, it is also impossible to obtain a sufficient emission intensity when the film thickness of the phosphor layer goes outside the range of 0.6 - 2.6 μ m.

Before the above phosphor layer was formed, the present inventors flew a current of 0.5.mA in the forward bias direction and obtained an emission spectrum having a peak wavelength in an ultraviolet region of approximately 200 - 400 μ m as illustrated in Figure 3. Therefore, the present inventors conducted experiments to form various phosphor layers having different grain demisters and film thickness above a pn junction and achieved the above inventions.

Below, the present invention will be explained in further details referring to Figure 1.

In the figure, numeral 11 denotes a p-type boron nitride crystal layer (p-type layer) containing a small quantity of Be. An n-type boron nitride crystal layer (n-type layer) 12 containing a small quantity of Si is formed on p-type layer 11. Here, above p-type layer 11 and n-type layer 12 are collectively called the base. On the sides of the base, granular phosphor layers 13 consisting of grains with a 0.3 - 13 μ m grain diameter are formed. Further, phosphor layers 13 do

not have to be formed to surround the entire sides of the base. It will suffice as long as the layers cover the junction between p-type layer 11 and n-type layer 12. Electrodes 14 and 15 are formed on the upper-and-lower surfaces of the above base, Respectively.

(Operations)

According to the present invention, solid state light emitting devices which provide various emission colors while being equipped with the same pn junction can be formed through forming various phosphor layers having different grain demisters and a different film thickness on the pn junction.

(Example 1)

Self-activating phosphor $MgWO_4$ was stirred and mixed in a solution consisting of 6% by weight of nitrocellulose, 2.5% by weight of ethanol, 86.5% by weight of butyl acetate and 5.0% by weight of diethyl phthalate. Next, the grains of $MgWO_4$ were applied on the sides of a base containing a pn junction as described above, heated to 400°C and then, cooled down to room temperature to form phosphor layers. Thus, solid state light emitting devices were obtained.

When an electrical of 20V was applied between electrodes and a current of 2mA was flown in the forward bias direction in the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength at 480nm was obtained, and a blue emission was observed. Further, phosphor layers with $MgWO_4$ particles having different grain diameters were formed on a pn junction in the same way as above, respectively. Afterward, an emission spectrum was measured and the relative emission intensity at the peak wavelength at 400nm was obtained. The relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 4 was obtained. According to the same figure, the emission efficiency of the phosphors was very poor when the phosphor grain diameter was than 0.6 μm or less. With this diameter, the efficiency decreased to 20% or less of that with the phosphor grain diameter of approximately 4.0 μm which is capable of producing the highest emission intensity, the phosphor rarely contributed for the emission. On the other hand, the relative emission intensity also decreased to 20% or less when the phosphor grain diameter was 11 μm or more, and the phosphor's contribution to the emission was slight. Based on the above, it is preferable that the diameter of $MgWO_4$ grains making up the phosphor layers be 0.6-11 μm .

(Example 2)

Self-activating phosphor $CaWO_4$ as sample powder was dispersed in an organic solution, and stirred and mixed in the same way as the Example 1. Next, the particles of $CaWO_4$ were

applied on the sides of a base containing a pn junction as described above, heated to 470 °C and then, cooled down to room temperature to form phosphor layers. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 30V was applied between electrodes and a current of 3mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength at approximately 415nm was obtained, and a blue emission was observed.

Further, phosphor layers with CaWO_4 particles having different grain diameters were formed on a pn junction in the same way as above, respectively. Afterward, an emission spectrum was measured and the relative emission intensity at the peak wavelength of 480nm was obtained. The relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 5 was obtained. According to the same figure, the highest emission intensity was obtained when the phosphor grain diameter was approximately 6 μm . However, the emission intensity decreased to 20% or less when the phosphor grain diameter was 2 μm or less, or 13 μm or more as is the case with MgWO_4 . Therefore, it is preferable that the diameter of grains in phosphor layers be 2- 13 μm when utilizing CaWO_4 phosphor.

(Example 3)

Through employing a phosphor $\text{Zn}_2\text{SiO}_4\text{: Mn}$, particles of this material were applied on the sides of a base containing a pn junction, and phosphor layers made of this material were formed in the same way as in Example 1. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 25V was applied between electrodes and a current of 2.5mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength of 525 nm was obtained, and a green emission was observed.

Further, the particle diameter of the phosphor was varied and the relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 6 was obtained. According to the same figure, the highest emission intensity was obtained when the phosphor grain diameter was around 5 μm . However, the emission intensity decreased to 20% or less, and the phosphor did not contribute for the emission when the phosphor grain diameter was 1.3 μm or less, or 13 μm or more. Therefore, it is preferable that the diameter of grains in phosphor layers be 1.3-13 μm when utilizing $\text{Zn}_2\text{SiO}_4\text{: Mn}$ phosphor.

(Example 4)

Through employing a phosphor $\text{Y}_2\text{O}_3\text{:Eu}$, particles of this material were applied on the sides of a base containing a pn junction, and phosphor layers made of this material were formed in the same way as the Example 1. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 30V was applied between electrodes and a current of 3.0mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength of 611 nm was obtained, and a green emission was observed.

Further, the relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 7 was obtained while changing the phosphor grain diameter. According to the same figure, the highest emission intensity was obtained when the phosphor grain diameter was around $4.2\mu\text{m}$. However, the emission intensity decreased to 20% or less, and the phosphor did not contribute for the emission when the phosphor grain diameter was $0.7\mu\text{m}$ or less, or $11\mu\text{m}$ or more. Therefore, it is preferable that the diameter of grains in phosphor layers be $0.7\text{--}11\mu\text{m}$ when utilizing $\text{Y}_2\text{O}_3\text{:Eu}$ phosphor.

(Example 5)

Self-activating phosphor MgWO_4 was put into a vacuum bell jar, and the vacuum was pumped to around 1×10^{-6} - 6×10^{-6} mmHg. Ar gas was introduced into the above vacuum bell jar, and MgWO_4 powder was sputtered in a 2×10^{-6} ~ 2×10^{-6} mmHg Ar atmosphere. Phosphor layers with a desired thickness were formed on a part of pn junction set up on the opposite side of MgWO_4 powder inside the same vacuum bell jar through a sputtering method. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 20V was applied between electrodes and a current of 2mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength of 480 nm was obtained, and a blue emission was observed. Further, MgWO_4 thin film phosphor layers with different film thicknesses were formed on a pn junction in the same way as above, respectively. Afterward, an emission spectrum was measured and the relative emission intensity at the peak wavelength of 480nm was obtained. The relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 8 was obtained. According to the same figure, the emission efficiency of the phosphors was very poor when the phosphor grain diameter was $0.6\mu\text{m}$ or less. The efficiency decreased to 20% or less of that with the phosphor grain diameter of around $1 \mu\text{m}$ which was capable of producing the highest emission intensity, and the phosphor rarely contributed for the emission. On the other hand, the relative emission intensity also decreased to 20% or less when the phosphor grain diameter was $2.6 \mu\text{m}$ or more, and the phosphor's

contribution to the emission was slight. Based on the above, it is preferable that the diameter of MgWO_4 grains in phosphor layers be 0.6-2.6 μm .

(Example 6)

Self-activating phosphor CaWO_4 as sample powder was applied on the sides of a base containing a pn junction as described above through the vacuum sputtering method in the same way as the Example 5, and phosphor layers were formed. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 30V was applied between electrodes and a current of 3mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength of around 415nm was obtained, and a blue emission was observed.

Further, CaWO_4 particle phosphor layers with different film thicknesses were formed on a pn junction in the same way as above, respectively. Afterward, an emission spectrum was measured and the relative emission intensity at the peak wavelength was obtained. The relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 9 was obtained. According to the same figure, the highest emission intensity was obtained when the phosphor grain film thickness was around 1.6 μm . However, the emission intensity decreased to 20% or less when the film thickness was 0.6 μm or less, or 2.6 μm or more as in the case with MgWO_4 . Therefore, it is preferable that the diameter of grains in phosphor layers be 0.6-2.6 μm when utilizing CaWO_4 phosphor.

(Example 7)

Through employing a phosphor $\text{Zn}_2\text{SiO}_4:\text{Mn}$, particles of this material were applied on the sides of a base containing a pn junction, and phosphor layers made of this material were formed in the same way as the Example 5. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 25V was applied between electrodes and a current of 2.5mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength at 525 nm was obtained, and a green emission was observed.

Further, the relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 10 was obtained while changing the film thickness of the phosphor layers. According to the same figure, the highest emission intensity was obtained when the phosphor film thickness was around 1.4 μm . However, the emission intensity decreased to 20% or less when the film thickness was 0.4 μm or less, or 3.0 μm or more, and the phosphor's

contribution to the emission was slight. Therefore, it is preferable that the diameter of grains in phosphor layers be 0.4-3.0 μ m when utilizing $Zn_2SiO_4:Mn$ phosphor.

(Example 8)

Through employing a phosphor $Y_2O_3:Eu$, particles of this material were applied on the sides of a base containing a pn junction, and phosphor layers made of this material were formed in the same way as the Example 5. Thus, solid state light emitting devices were obtained.

When an electrical voltage of 30V was applied between electrodes and a current of 3.0mA was flown in the forward bias direction of the solid state light emitting devices which were obtained through the above procedure, an emission spectrum with a peak wavelength at 611 nm was obtained, and a green emission was observed.

Further, the relationship between the relative emission intensity and phosphor grain diameter as illustrated in Figure 11 was obtained while changing the film thickness of the phosphor layers. According to the same figure, the highest emission intensity was obtained when the phosphor film thickness was around 1 μ m. However, the emission intensity decreased to 20% or less when the film thickness was 0.3 μ m or less, or 3.0 μ m or more, and the phosphor's contribution to the emission was slight. Therefore, it is preferable that the diameter of grains in phosphor layers be 0.3-3.0 μ m when utilizing $Y_2O_3:Eu$ phosphor.

[Advantages of the Invention]

According to the present invention described above in detail, solid state light emitting devices having various emission colors, while being equipped with the same pn junction, can be provided.

4. Brief Explanation of the Figures

Figure 1 is a cross section of an example of a solid state light emitting device of the present invention. Figure 2 is a cross section of a conventional solid state light emitting device. Figure 3 shows an emission spectrum of emission from a pn junction surface of a solid state light emitting device related to the present invention. Figures 4-7 show the relationship between the relative emission intensity and phosphor grain diameter measured through applying particle phosphor layers with different grain diameters, respectively. Figures 8-11 show the relationship between the relative emission intensity and phosphor film thickness measured through applying thin film phosphor layers with different film thicknesses, respectively.

- | | |
|--|--|
| 11: P-type boron nitride crystal layer | 12: NP -type boron nitride crystal layer |
| 13: Phosphor layers | 14 and 15: Electrode |

Patent Applicant Agent:

Lawyer

Takehiko Suzue

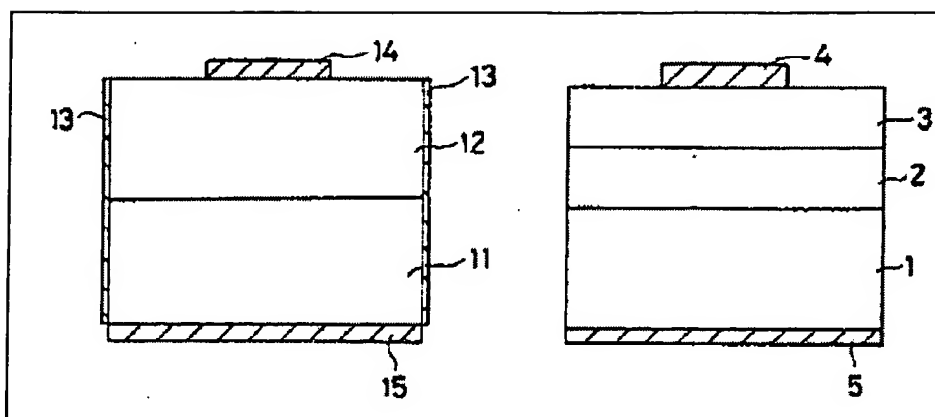
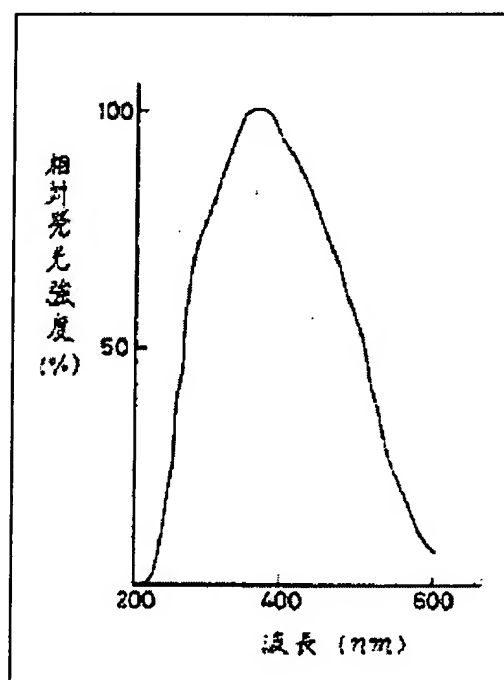


Figure 1

Figure 2

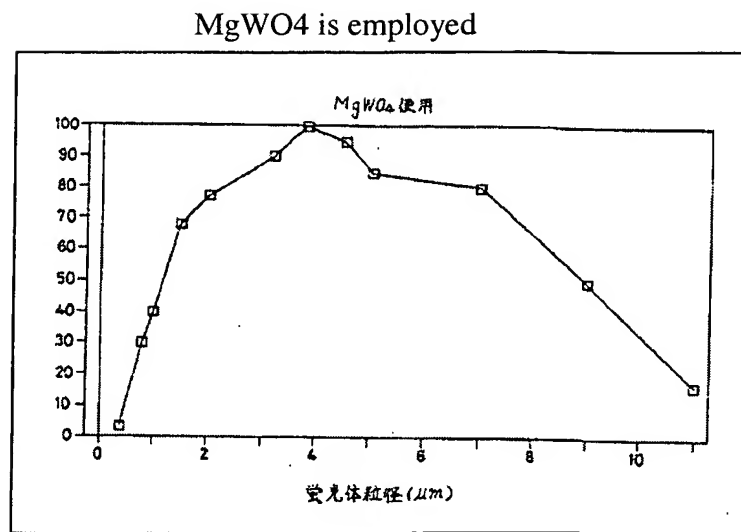
Relative emission
intensity (%)



Wavelength (microns)

Figure 3

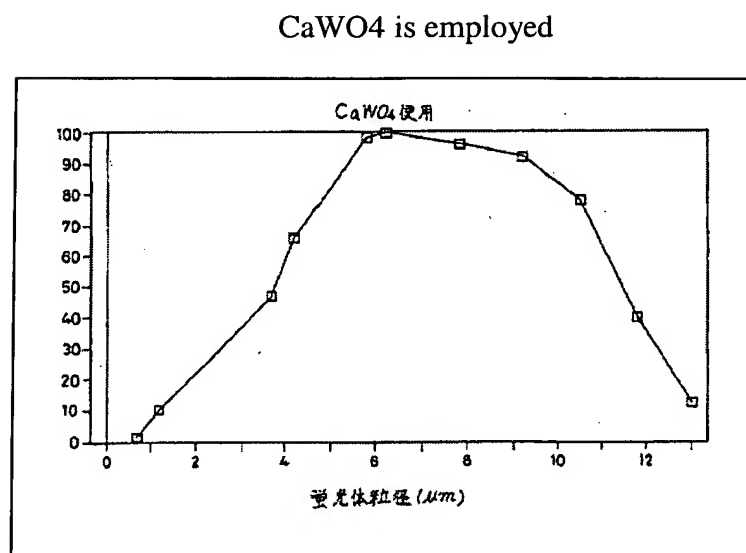
Relative emission
intensity (%)



Phosphor particle diameter (microns)

Figure 4

Relative emission
intensity (%)

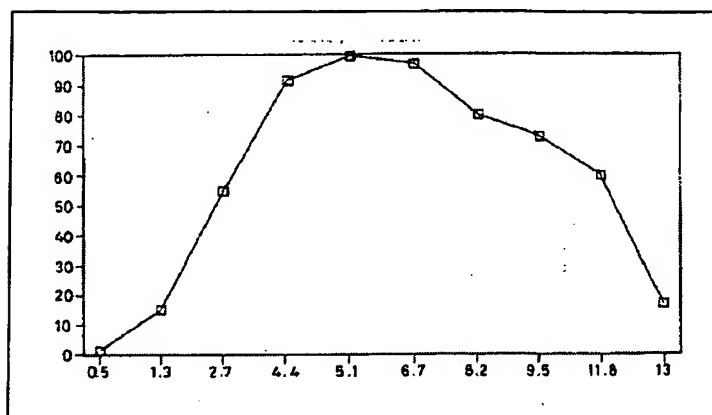


Phosphor particle diameter (microns)

Figure 5

Zn_2SiO_4 : Mn is employed

Relative emission
intensity (%)

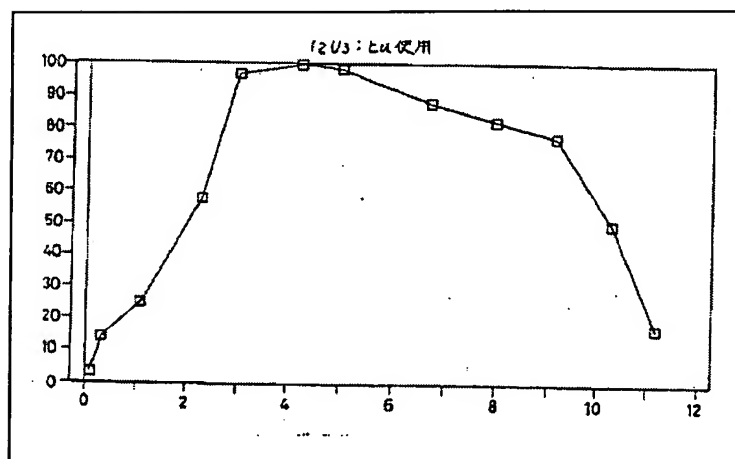


Phosphor particle diameter (microns)

Figure 6

Y_2O_3 :Eu is employed

Relative emission
intensity (%)

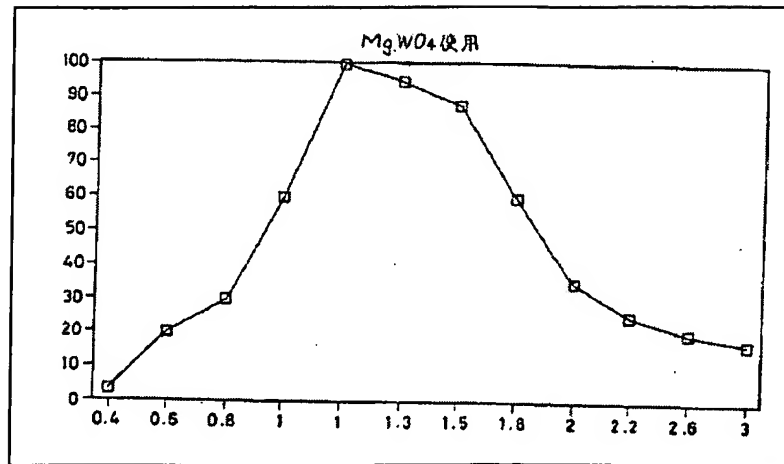


Phosphor particle diameter (microns)

Figure 7

MgWO₄ is employed

Relative emission
intensity (%)

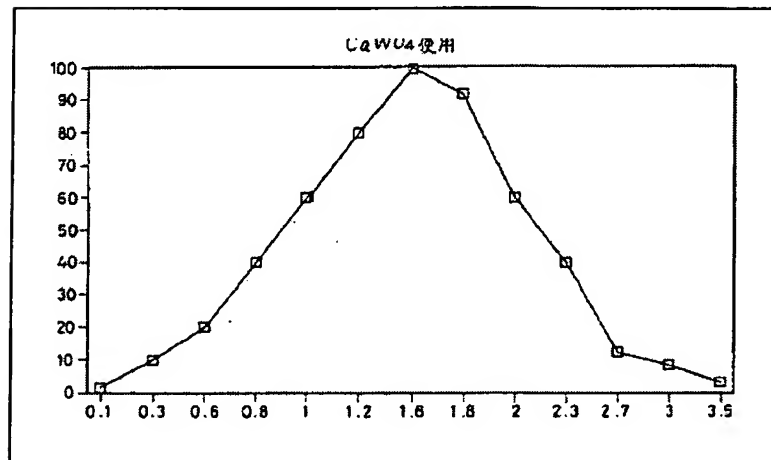


Phosphor layer thickness (microns)

Figure 8

CaWO₄ is employed

Relative emission
intensity (%)

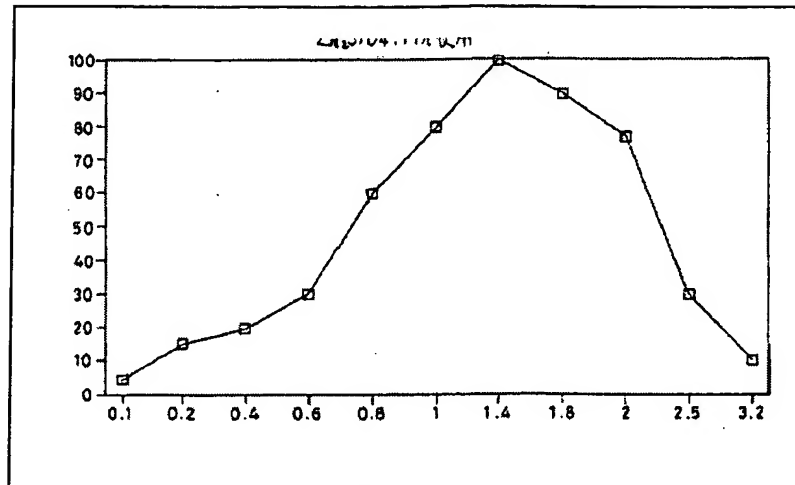


Phosphor layer thickness (microns)

Figure 9

Zn₂SiO₄: Mn is employed

Relative emission
intensity (%)

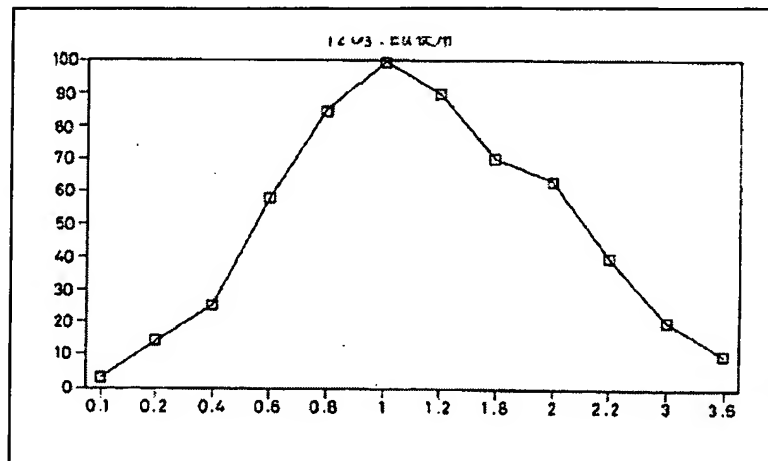


Phosphor layer thickness (microns)

Figure 10

Y₂O₃:Eu is employed

Relative emission
intensity (%)



Phosphor layer thickness (microns)

Figure 11